# Chapter 1

# GENERAL

## 1.1 INTRODUCTION

1.1.1 In view of the vital function of runways in providing for safe and efficient aircraft landings and take-offs, it is imperative that their design take into account the operational and physical characteristics of the aeroplanes expected to use the runway, as well as engineering and economic considerations.

1.1.2 The aerodrome elements associated with runways which are directly related to the landing and take-off of aeroplanes are: runway strips, runway shoulders, stopways, clearways and runway end safety areas. This manual concerns the provision of runways and these associated elements and summarizes specifications and guidance material relating to their geometric design. Pavement strength design aspects are covered in the *Aerodrome Design Manual* (Doc 9157), Part 3 — *Pavements*.

## 1.2 EXPLANATION OF TERMS

***Aerodrome.*** A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

***Aerodrome elevation.*** The elevation of the highest point of the landing area.

***Clearway.*** A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height.

***Displaced threshold.*** A threshold not located at the extremity of a runway.

***Frangible object.*** An object of low mass designed to break, distort or yield on impact so as to present the minimum hazard to aircraft.

***Instrument runway.*** One of the following types of runways intended for the operation of aircraft using instrument approach procedures:

a) Non-precision approach runway. An instrument runway served by visual aids and a non-visual aid providing at least directional guidance adequate for a straight-in approach.

b) Precision approach runway, category I. An instrument runway served by ILS and/or MLS and visual aids intended for operations with a decision height not lower than 60 m (200 ft) and either a visibility not less than 800 m or a runway visual range not less than 550 m.

c) Precision approach runway, category II. An instrument runway served by ILS and/or MLS and visual aids intended for operations with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft) and a runway visual range not lower than 350 m.

d) Precision approach runway, category III. An instrument runway served by ILS and/or MLS to and along the surface of the runway and:

A — intended for operations with a decision height lower than 30 m (100 ft), or no decision height and a runway visual range not less than 200 m.

B — intended for operations with a decision height lower than 15 m (50 ft), or no decision height and a runway visual range less than 200 m but not less than 50 m.

C — intended for operations with no decision height and no visual range limitations.

***Landing area.*** That part of a movement area intended for the landing or take-off of aircraft.

***Manoeuvring area.*** That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons.

***Movement area.*** That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the manoeuvring area and the apron(s).

***Non-instrument runway.*** A runway intended for the operation of aircraft using visual approach procedures.

***Obstacle.*** All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that are located on an area intended for the surface movement of aircraft or that extend above a defined surface intended to protect aircraft in flight.

***Primary runway(s).*** Runway(s) used in preference to others whenever conditions permit.

***Runway.*** A defined rectangular area on a land aerodrome prepared for the landing and take-off of aircraft.

***Runway end safety area (RESA).*** An area symmetrical about the extended runway centre line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway.

***Runway strip.*** A defined area including the runway and stopway, if provided, intended:

a) to reduce the risk of damage to aircraft running off a runway; and

b) to protect aircraft flying over it during take-off or landing operations.

***Shoulder.*** An area adjacent to the edge of a pavement so prepared as to provide a transition between the pavement and the adjacent surface.

***Threshold.*** The beginning of that portion of the runway usable for landing.

# Chapter 2

# CONFIGURATION CONSIDERATIONS

## 2.1 FACTORS RELATING TO THE SITING, ORIENTATION AND NUMBER OF RUNWAYS

### General

*Note.— Flexibility to accommodate any future expansion of the runway infrastructure is fundamental to the planning and design of airports.*

2.1.1 Many factors affect the determination of the siting, orientation and number of runways. The more important factors are:

a) weather, in particular the runway/aerodrome usability factor, as determined by wind distribution, and the occurrence of localized fogs;

b) topography of the aerodrome site and its surroundings;

c) type and amount of air traffic to be served, including air traffic control aspects;

d) aeroplane performance considerations; and

e) environmental considerations, particularly noise.

2.1.2 The primary runway, to the extent other factors permit, should be oriented in the direction of the prevailing wind. All runways should be oriented so that approach and departure areas are free of obstacles and, preferably, so that aircraft are not directed over populated areas.

2.1.3 The number of runways must be sufficient to meet air traffic demands, which consist of the number of aircraft arrivals and departures, and the mixture of aircraft types, to be accommodated in one hour during the busiest periods. The decision as to the total number of runways to be provided should also take into account the aerodrome usability factor and economic considerations.

### Type of operation

2.1.4 Particular attention should be paid to whether the aerodrome is to be used in all meteorological conditions or only in visual meteorological conditions, and whether it is intended for use by day and night or only by day.

2.1.5 When a new instrument runway is being located, particular attention needs to be given to areas over which aeroplanes will be required to fly when following instrument approach and missed approach procedures, so as to ensure that obstacles in these areas or other factors will not restrict the operation of the aeroplanes for which the runway is intended.

**Wind**

2.1.6 The number and orientation of runways at an aerodrome should be such that the usability factor of the aerodrome is not less than 95 per cent for the aeroplane that the aerodrome is intended to serve.

2.1.7 In the application of the 95 per cent usability factor it should be assumed that landing or take-off of aeroplanes is, in normal circumstances, precluded when the cross-wind component exceeds:

— 37 km/h (20 kt) in the case of aeroplanes whose reference field length is 1 500 m or over, except that when poor runway braking action owing to an insufficient longitudinal coefficient of friction is experienced with some frequency, a cross-wind component not exceeding 24 km/h (13 kt) should be assumed;

— 24 km/h (13 kt) in the case of aeroplanes whose reference field length is 1 200 m or up to but not including 1 500 m; and

— 19 km/h (10 kt) in the case of aeroplanes whose reference field length is less than 1 200 m.

2.1.8 The selection of data to be used for the calculation of the usability factor should be based on reliable wind distribution statistics that extend over as long a period as possible, preferably of not less than five years. The observations used should be made at least eight times daily and spaced at equal intervals of time, and should take into account the following:

a) wind statistics used for the calculation of the usability factor are normally available in ranges of speed and direction, and the accuracy of the results obtained depends, to a large extent, on the assumed distribution of observations within these ranges. In the absence of any sure information as to the true distribution, it is usual to assume a uniform distribution since, in relation to the most favourable runway orientations, this generally results in a slightly conservative figure for the usability factor;

b) the maximum mean cross-wind components given in 2.1.7 refer to normal circumstances. There are some factors which may require that a reduction of those maximum values be taken into account at a particular aerodrome. These include:

   1) the wide variations which may exist, in handling characteristics and maximum permissible cross-wind components, among diverse types of aeroplanes (including future types) within each of the three groups given in 2.1.7;

   2) prevalence and nature of gusts;

   3) prevalence and nature of turbulence;

   4) the availability of a secondary runway;

   5) the width of runways;

   6) the runway surface conditions – water, snow, slush and ice on the runway materially reduce the allowable cross-wind component; and

   7) the strength of the wind associated with the limiting cross-wind component.

2.1.9 The 95 per cent criterion recommended by Annex 14, Volume I is applicable to all conditions of weather; nevertheless, it is useful to examine wind speed and direction for different visibility conditions. Weather records can usually be obtained from government weather bureaux. The velocities are generally grouped into 22.5 degree increments (16 points of the compass). The weather records contain the percentage of time certain combinations of ceiling and visibility occur (e.g. ceiling, 500 to 274 m; visibility, 4.8 to 9.7 km), and the percentage of time winds of a specific velocity occur from different directions; for example NNE, 2.6 to 4.6 kt. The directions are relative to true north. Often wind data for a new location have not been recorded. If that is the case, records of nearby measuring stations should be consulted. If the surrounding area is fairly level, the records of these stations should indicate the winds at the site of the proposed aerodrome. However, if the terrain is hilly, the wind pattern often is dictated by the topography, and it is dangerous to utilize the records of stations some distance from the site. In that event, a study of the topography of the region and consultation with local residents may prove useful but a wind study of the site should be initiated. Such a study would involve the installation of wind gauges and the keeping of wind records. Guidance material on the preparation and analysis of wind data for aerodrome planning purposes is given in the *Airport Planning Manual* (Doc 9184) Part 1 — *Master Planning*.

### Visibility conditions

2.1.10 Wind characteristics under poor visibility conditions are often quite different from those experienced under good visibility conditions. Therefore a study should be made of the wind conditions occurring with poor visibility and/or low cloud base at the aerodrome, including the frequency of occurrence and the accompanying wind direction and speed.

### Topography of the aerodrome site, its approaches and surroundings

2.1.11 The topographical features of the aerodrome and its surroundings should be examined. In particular the following should be reviewed:

a) compliance with the obstacle limitation surfaces;

b) current and future land use. The orientation and layout should be selected so as to protect as far as possible the particularly sensitive areas such as residential, school and hospital zones from the discomfort caused by aircraft noise;

c) current and future runway lengths to be provided;

d) construction costs; and

e) the possibility of installing suitable non-visual and visual aids for approach-to-land.

### Air traffic in the vicinity of the aerodrome

2.1.12 When considering the siting of runways the following should be taken into account:

a) proximity of other aerodromes or ATS routes;

b) traffic density; and

c) air traffic control and missed approach procedures.

### Environmental factors

2.1.13 The effect of a particular runway alignment on wild life, the general ecology of the area, and noise-sensitive areas of communities should be considered.

2.1.14 The noise level produced by aircraft operations at and around the aerodrome is generally considered a primary environmental cost associated with the facility. Most noise exposure lies within the land area immediately beneath and adjacent to the aircraft approach and departure paths. Noise levels are generally measured through some formulation of decibel level, duration and number of occurrences. A large number of noise measuring techniques exist (see Annex 16 — *Environmental Protection* and *Recommended Method for Computing Noise Contours around Airports* (Cir 205)). Proper site selection and adjacent land use planning can serve to greatly reduce and possibly eliminate the noise problem associated with the aerodrome.

### Parallel runways

2.1.15 The number of runways to be provided in each direction depends on the forecast of aircraft movements (see the *Airport Planning Manual* (Doc 9184), Part 1).

2.1.16 *VMC operations*. Where parallel runways are provided for simultaneous use under visual meteorological conditions only, the minimum distance between their centre lines should be:

— 210 m where the higher code number is 3 or 4;

— 150 m where the higher code number is 2; and

— 120 m where the higher code number is 1.

2.1.17 *IMC operations*. Where parallel runways are provided for simultaneous operations under instrument meteorological conditions, the minimum separation distance between their centre lines should be:

— 1 035 m for independent parallel approaches;

— 915 m for dependent parallel approaches;

— 760 m for independent parallel departures;

— 760 m for segregated parallel operations;

except that:

a) for segregated parallel operations the specified separation distance:

   1) may be decreased by 30 m for each 150 m that the arrival runway is staggered toward the arriving aircraft, to a minimum of 300 m; and

   2) should be increased by 30 m for each 150 m that the arrival runway is staggered away from the arriving aircraft;

b) lower separation distances than those specified above may be applied if, after aeronautical study, it is determined that such lower separation distances would not affect the safety of operations of aircraft.

2.1.18 Guidance on planning and conducting simultaneous operations on parallel or near-parallel instrument runways is contained in the *Manual of Simultaneous Operations on Parallel or Near-Parallel Instrument Runways (SOIR)* (Doc 9643).

### Terminal area between parallel runways

2.1.19 To minimize taxi operations across active runways and to better utilize the area between the parallel runways, the terminal area and other operational areas may be placed between parallel runways. To accommodate these areas, greater separation distances than those recommended in the preceding paragraph may be required.

## 2.2 LOCATION OF THRESHOLD

2.2.1 The threshold is normally located at the extremity of a runway, if there are no obstacles penetrating above the approach surface. In some cases, however, due to local conditions it may be desirable to displace the threshold permanently (see 2.2.3). When studying the location of a threshold, consideration should also be given to the height of the ILS reference datum and the determination of the obstacle clearance limits. (Specifications concerning the height of the ILS reference datum are given in Annex 10, Volume I.)

2.2.2 In determining that no obstacle penetrates above the approach surface, account should be taken of mobile objects (vehicles on roads, trains, etc.) at least within that portion of the approach area within 1 200 m longitudinally from the threshold and of an overall width of not less than 150 m.

2.2.3 If an object extends above the approach surface and the object cannot be removed, consideration should be given to displacing the threshold permanently.

2.2.4 To meet the obstacle limitation objectives of Annex 14, Volume I, Chapter 4, the threshold should ideally be displaced down the runway for the distance necessary to ensure that the approach surface is clear of obstacles.

2.2.5 However, displacement of the threshold from the runway extremity will inevitably cause reduction of the landing distance available, and this may be of greater operational significance than penetration of the approach surface by marked and lighted obstacles. A decision to displace the threshold, and the extent of such displacement, should therefore have regard to an optimum balance between the considerations of clear approach surfaces and adequate landing distance. In deciding this question, account will need to be taken of the types of aeroplanes which the runway is intended to serve, the limiting visibility and cloud base conditions under which the runway will be used, the position of the obstacles in relation to the threshold and extended centre line and, in the case of a precision approach runway, the significance of the obstacles to the determination of the obstacle clearance limit.

2.2.6 Notwithstanding the consideration of landing distance available, the selected position for the threshold should not be such that the obstacle-free surface to the threshold is steeper than 3.3 per cent where the code number is 4 or steeper than 5 per cent where the code number is 3.

———————

# Chapter 3

# RUNWAY LENGTH CONSIDERATIONS

## 3.1 FACTORS AFFECTING THE LENGTH OF RUNWAYS

3.1.1 Factors which have a bearing on the runway length to be provided are:

a) performance characteristics and operating masses of the aeroplanes to be served;

b) weather, particularly surface wind and temperature;

c) runway characteristics such as slope and surface condition; and

d) aerodrome location factors, for example, aerodrome elevation which affects the barometric pressure and topographical constraints.

3.1.2 The relationship between runway length and aeroplane performance characteristics is discussed in Chapter 4. The greater the head wind down a runway, the shorter the runway length required by an aeroplane taking off or landing. Conversely, a tail wind increases the length of runway required. The higher the temperature, the longer the runway required because higher temperatures create lower air densities resulting in lower output of thrust and reduced lift. The effect of runway slopes on runway length requirements is discussed in detail in Appendix 2, however it is evident that an aeroplane taking off on an uphill gradient requires more runway length than it would on a level or downhill gradient; the specific amount depends on the elevation of the aerodrome and the temperature. All other factors being equal, the higher the elevation of the aerodrome with correspondingly lower barometric pressure, the longer the runway required. The runway length which can be provided at an aerodrome may be constrained by property boundaries or topographical features such as mountains, the sea or steep valleys.

## 3.2 ACTUAL LENGTH OF RUNWAYS

### Primary runways

3.2.1 Except where a runway is associated with a stopway and/or clearway, the actual runway length to be provided for a primary runway should be adequate to meet the operational requirements of the aeroplanes for which the runway is intended and should be not less than the longest length determined by applying the corrections for local conditions to the operations and performance characteristics of the relevant aeroplanes.

3.2.2 Both take-off and landing requirements need to be considered when determining the length of runway to be provided and the need for operations to be conducted in both directions of the runway. Local conditions that may need to be considered include elevation, temperature, runway slope, humidity and the runway surface characteristics.

3.2.3 When performance data on aeroplanes for which the runway is intended are not known, the actual length of a primary runway may be determined by application of general correction factors as described in 3.5. However, it is advisable that the aeroplane manufacturers document entitled Aeroplane Characteristics for Airport Planning — NAS 3601 be consulted for the most up-to-date information.

**Secondary runways**

3.2.4 The length of a secondary runway should be determined similarly to primary runways except that it needs only to be adequate for those aeroplanes which require to use that secondary runway in addition to the other runway or runways in order to obtain a usability factor of at least 95 per cent.

3.2.5 Flight manuals providing data on aeroplane operational requirements and performance characteristics are available for most modern aeroplanes. Aeroplane performance curves and tables for landing and take-off operations have also been developed for basic runway length planning purposes. Information on these aeroplane performance curves and tables is given in Appendix 3.

## 3.3 RUNWAYS WITH STOPWAYS AND/OR CLEARWAYS

3.3.1 Where a runway is associated with a stopway or clearway, an actual runway length less than that resulting from application of 3.2.2 or 3.2.3, as appropriate, may be considered satisfactory, but in such a case any combination of runway, stopway and/or clearway provided should permit compliance with the operational requirements for take- off and landing of the aeroplanes the runway is intended to serve.

3.3.2 The decision to provide a stopway and/or a clearway as an alternative to an increased length of runway will depend on the physical characteristics of the area beyond the runway end, and on the operating performance requirements of the prospective aeroplanes. The runway, stopway and clearway lengths to be provided are determined by the aeroplane take-off performance, but a check should also be made of the landing distance required by the aeroplanes using the runway to ensure that adequate runway length is provided for landing. The length of a clearway, however, cannot exceed half the length of take-off run available.

## 3.4 CALCULATION OF DECLARED DISTANCES

3.4.1 The introduction of stopways and clearways and the use of displaced thresholds on runways has created a need for accurate information regarding the various physical distances available and suitable for the landing and take-off of aeroplanes. For these purposes, the term “declared distances” is used with the following four distances associated with a particular runway:

a) Take-off run available (TORA), i.e. the length of runway declared available and suitable for the ground run of an aeroplane taking off.

b) Take-off distance available (TODA), i.e. the length of the take-off run available plus the length of the clearway, if provided.

c) Accelerate stop distance available (ASDA), i.e. the length of the take-off run available plus the length of the stopway, if provided.

d) Landing distance available (LDA), i.e. the length of runway which is declared available and suitable for the ground run of an aeroplane landing.

3.4.2 Annex 14, Volume I, calls for the calculation of declared distances for a runway intended for use by international commercial air transport, and Annex 15 calls for the reporting of declared distances for each direction of the runway in the State Aeronautical Information Publication (AIP). Figure 3-1 illustrates typical cases, and Figure 3-2 shows a tabulation of declared distances.

3.4.3 Where a runway is not provided with a stopway or clearway and the threshold is located at the extremity of the runway, the four declared distances should normally be equal to the length of the runway as shown in Figure 3-1A.

3.4.4 Where a runway is provided with a clearway (CWY), then the TODA will include the length of clearway as shown in Figure 3-1B.

3.4.5 Where a runway is provided with a stopway (SWY), then the ASDA will include the length of stopway as shown in Figure 3-1C.

3.4.6 Where a runway has a displaced threshold, then the LDA will be reduced by the distance the threshold is displaced as shown in Figure 3-1D. A displaced threshold affects only the LDA for approaches made to that threshold; all declared distances for operations in the reciprocal direction are unaffected.

3.4.7 Figures 3-1B through 3-1D illustrate a runway provided with a clearway, a stopway or having a displaced threshold. Where more than one of these features exist then more than one of the declared distances will be modified - but the modification will follow the same principle illustrated. Figures 3-1E and 3-1F illustrate two situations where all these features exist.

3.4.8 A suggested format for providing information on declared distances is given in Figure 3-2. If a runway direction cannot be used for take-off or landing, or both, because it is operationally forbidden, then this should be declared and the words “not usable” or the abbreviation “NU” entered.

3.4.9 Where provision of a runway end safety area may involve encroachment in areas where it would be particularly prohibitive to implement, and the appropriate authority considers a runway end safety area essential, consideration may have to be given to reducing some of the declared distances.

## 3.5 RUNWAY LENGTH CORRECTIONS FOR ELEVATION, TEMPERATURE AND SLOPE

3.5.1 As stated in 3.2.3, when the appropriate flight manual is not available the runway length must be determined by applying general correction factors. As a first step, a basic length should be selected for the runway adequate to meet the operational requirements of the aeroplanes for which the runway is intended. This basic length is a runway length selected for aerodrome planning purposes which is required for take-off or landing under standard atmospheric conditions for zero elevation, zero wind and zero runway slope.

3.5.2 The basic length selected for the runway should be increased at the rate of 7 per cent per 300 m elevation.

3.5.3 The length of runway determined under 3.5.2 should be further increased at the rate of 1 per cent for every 1°C by which the aerodrome reference temperature exceeds the temperature in the standard atmosphere for the aerodrome elevation (see Table 3-1). If, however, the total correction for elevation and

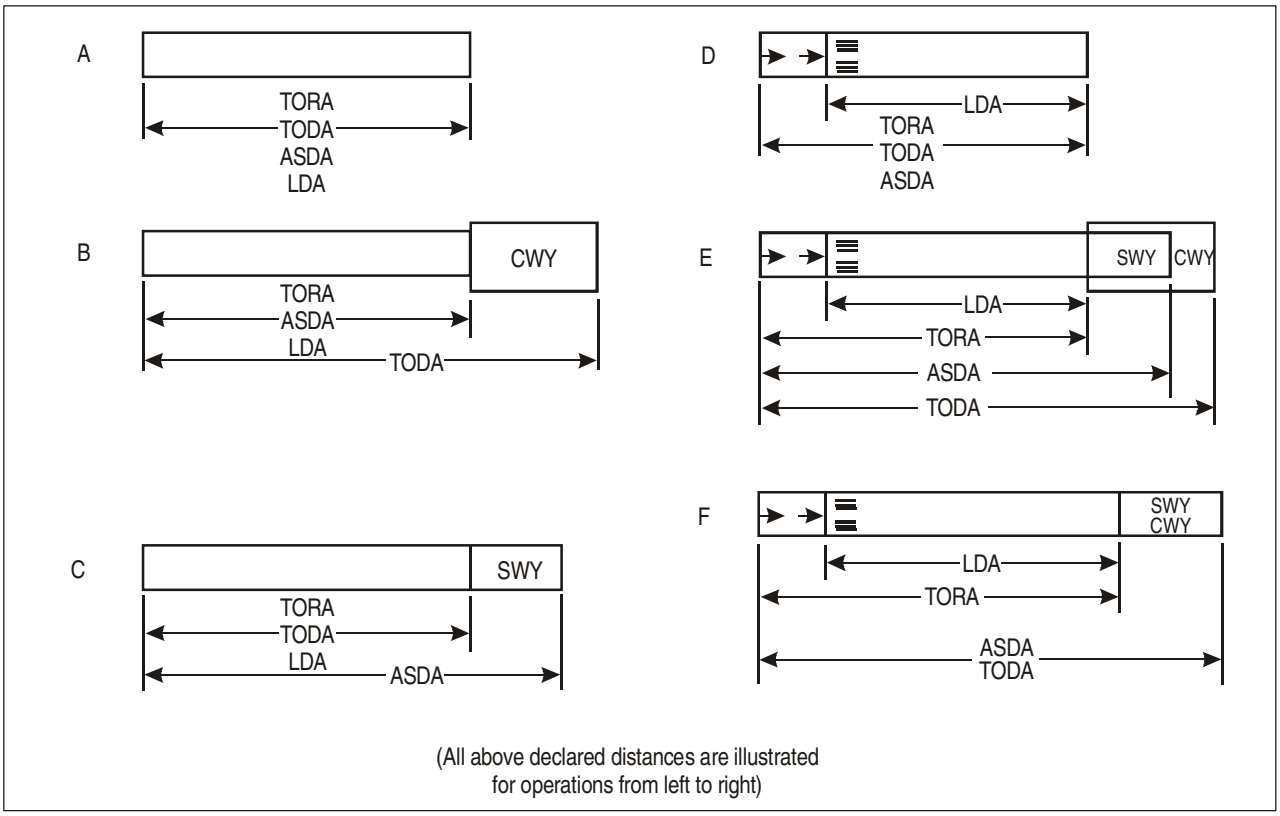
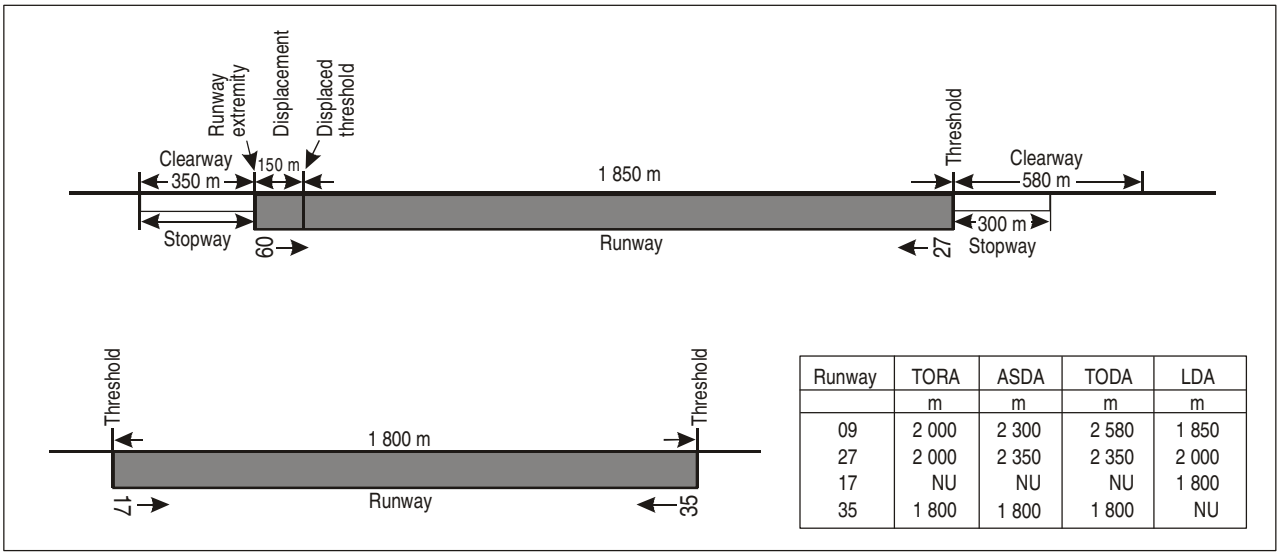



**Figure 3-1. Illustration of declared distances**




| Runway | TORA | ASDA | TODA | LDA |
|---|---|---|---|---|
| | m | m | m | m |
| 09 | 2 000 | 2 300 | 2 580 | 1 850 |
| 27 | 2 000 | 2 350 | 2 350 | 2 000 |
| 17 | NU | NU | NU | 1 800 |
| 35 | 1 800 | 1 800 | 1 800 | NU |

**Figure 3-2. Determination of declared distances**

temperature exceeds 35 per cent, the required corrections should be obtained by means of a specific study. The operational characteristics of certain aeroplanes may indicate that these correction constants for elevation and temperature are not appropriate, and that they may need to be modified by results of aeronautical study based upon conditions existing at the particular site and the operating requirements of such aeroplanes.

3.5.4 Where the basic length determined by take-off requirements is 900 m or over, that length should be further increased at the rate of 10 per cent for each 1 per cent of the runway slope as defined in 5.1.4.

3.5.5 At aerodromes where temperature and humidity are both high, some addition to the runway length determined under 3.5.4 may be necessary, even though it is not possible to give exact figures for the increased lengths required.

**Table 3-1. Table of Standard Atmosphere Values**

| Altitude (m) | Temperature (Centigrade) | Pressure ($Kg/m^3$) |
|---|---|---|
| 0 | 15.00 | 1.23 |
| 500 | 11.75 | 1.17 |
| 1 000 | 8.50 | 1.11 |
| 1 500 | 5.25 | 1.06 |
| 2 000 | 2.00 | 1.01 |
| 2 500 | –1.25 | 0.96 |
| 3 000 | –4.50 | 0.91 |
| 3 500 | –7.75 | 0.86 |
| 4 000 | –10.98 | 0.82 |
| 4 500 | –14.23 | 0.78 |
| 5 000 | –17.47 | 0.74 |
| 5 500 | –20.72 | 0.70 |
| 6 000 | –23.96 | 0.66 |

**Examples of the application of runway length corrections**

3.5.6 The following examples illustrate the application of the runway length corrections.

**Example 1:**

a) Data:

| | | |
|---|---|---|
| 1) | runway length required for landing at sea level in standard atmospheric conditions | 2 100 m |
| 2) | runway length required for take-off at a level site at sea level in standard atmospheric conditions | 1 700 m |
| 3) | aerodrome elevation | 150 m |
| 4) | aerodrome reference temperature | 24°C |
| 5) | temperature in the standard atmosphere for 150 m | 14.025°C |
| 6) | runway slope | 0.5% |

b) Corrections to runway take-off length:

1) runway take-off length corrected for elevation =

$$\left[1\,700 \times 0.07 \times \frac{150}{300}\right] + 1\,700 = \quad 1\,760 \text{ m}$$

2) runway take-off length corrected for elevation and temperature =

$$[1\,760 \times (24 - 14.025) \times 0.01\ ] + 1\,760 = \quad 1\,936 \text{ m}$$

3) runway take-off length corrected for elevation, temperature and slope =

$$[1\,936 \times 0.5 \times 0.10\ ] + 1\,936 = \quad 2\,033 \text{ m}$$

c) Correction to runway landing length:
runway landing length corrected for elevation =

$$\left[2\,100 \times 0.07 \times \frac{150}{300}\right] + 2\,100 = \quad 2\,174 \text{ m}$$

d) Actual runway length = 2 175 m

**Example 2:**

a) Data:

| | | |
|---|---|---|
| 1) | runway length required for landing at sea level in standard atmospheric conditions | 2 100 m |
| 2) | runway length required for take-off at a level site at sea level in standard atmospheric conditions | 2 500 m |
| 3) | aerodrome elevation | 150 m |
| 4) | aerodrome reference temperature | 24°C |
| 5) | temperature in the standard atmosphere for 150 m | 14.025°C |
| 6) | runway slope | 0.5% |

b) Correction to runway take-off length:

1) runway take-off length corrected for elevation =

$$\left[2\,500 \times 0.07 \times \frac{150}{300}\right] + 2\,500 = \quad 2\,588 \text{ m}$$

2) runway take-off length corrected for elevation and temperature =

$$\left[2\,588 \times (24 - 14.025) \times 0.01\right] + 2\,588 = \quad 2\,846 \text{ m}$$

3) runway take-off length corrected for elevation, temperature and slope =

$$\left[2\,846 \times 0.5 \times 0.10\right] + 2\,846 = \quad 2\,988 \text{ m}$$

c) Correction to runway landing length:
runway landing length corrected for elevation =

$$\left[2\,100 \times 0.07 \times \frac{150}{300}\right] + 2\,100 = \quad 2\,174 \text{ m}$$

d) Actual runway length = 2 988 m

---